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Effect of Brake Pad Design On Friction and Wear with Hard Particle Present

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Graphical abstract

Abstract

Brake pad and disc design are important factors in ensuring excellent brake performance. But, particles from the environment can easily enter and interrupt the braking process and reduce braking performance. Friction depends on the design and surface properties of the pad and the disc. Wear happens in the brake system as the pad and disc try to withstand the braking force during the braking process. An experiment using brake dynamometer is done in order to determine the design effects on friction and wear when hard particle are present during the braking process. The test used three different brake pad designs under medium sliding load condition. It is found that Design 2 with a middle line groove provides better and stable brake torque and friction performance compared to Design 1 and Design 3. Design 2 also gavethe smallestweight loss inthe wear analysis of the pad.

Keywords: pad design, friction, wear, hard particle

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■1.0 INTRODUCTION

Brake pad is designed so that the effective area of contact between the disc and the pad will be aswide as possible during braking [1-3]. The effective contact is important because it is the fundamental of braking operation. The disc is designed to absorb the heat that has been converted from kinetic energy without fail. The disc is expected to last long andthe braking to be smooth. Brake disc is designed to provide friction surface and also to absorb the heat and dissipate it. Bigger discs can absorb more heat compared to a smaller ones.

Most cars nowadays use disc brakes on the front wheel. Some use disc brakes on both front and rear wheels. However, the open design of disc brake and the presence of hard particles from the environment during braking can cause disturbance to the braking effectiveness due to increase or decrease of the friction of the system [4-6]. The contacts between the pad and disc can be reduced and this causes the contact area to lose grip and become unstable. Brake pad has steel backing plate with friction material bonded to the surface that is directly in contact to the brake disc. Brake pad is the mechanism and material to convert kinetic energy to thermal energy using frictional force. There are many types of brake pads such as very soft and aggressive for racing application and harder, more durable and less aggressive compounds for normal vehicles. The design of brake disc is also varied. There is solid cast iron and ventilated disc. The solid brake disc is strong and heavy but the ventilated disc helps to dissipate heat better. To avoid thermal stress, cracking and out of plane warping, the brake disc is mounted half loose to the hub with coarse spline.

During braking, the changes of friction coefficients between disc and pads will cause the pads to wear. In addition, Abdul Hamid *et al.* [3] stated that the presence of external particles may change the mating surfaces and give different values of the friction coefficients. Values of the coefficient of friction tend to fluctuate due to the existence of external particles such as silica sand and dust. Generally, the coefficient of friction should be high and stable to get the best braking effectiveness. Thus, the design of the pad and the disc is important and can be used to control friction levels and wear rates by trapping and wiping the wear debris from the brake interface. As the brake pads wear, the materials produced are in the form of particles. These wear particles are collectively referred to as wear debris. The wear debris generated during the sliding process can either be ejected or become friction film on the pad to assist friction and reduce wear.

Kukutschova *et al.* [7] reported that the wear of the brake lining depends on sliding speed, applied pressure and temperature. From the analysis, they show the wear debris formed a friction layer on surface of brake lining. Also, brake wear particle from the semi-metallic pads wereanalysed and found that the wear debris consists of elements of carbon, oxygen, aluminium, magnesium, sulphur, silicon, barium, antimony, iron, copper, calcium, potassium, zirconium and bromine.

(a) (b) (c)

Figure 1 Brake Pads of different designs for testing (a) Design 1,(b) Design 2 and (c) Design 3

Figure 2 Drag type brake dynamometer used for the test

This paper reports the experiment conducted to determine the effects of different brake pad designs on friction and wear when hard particles are present. For this experiment, particle feeder was designed to feed hard particlesinto the braking system

■2.0 EXPERIMENTAL DESIGN

The aim of this study is to evaluate the effect of brake pad designs on wear and friction with the influence of foreign hard particles. Three different brake pad designs from different manufacturers were selected for this test and all have the same bulk material properties. The pads are marked as Design 1, 2 and 3 as shown in Figure 1. Design 1 is a standard pad with no channel. Design 2 is a pad with a straight channel in the middle and design 3 is a pad with slanted channel.

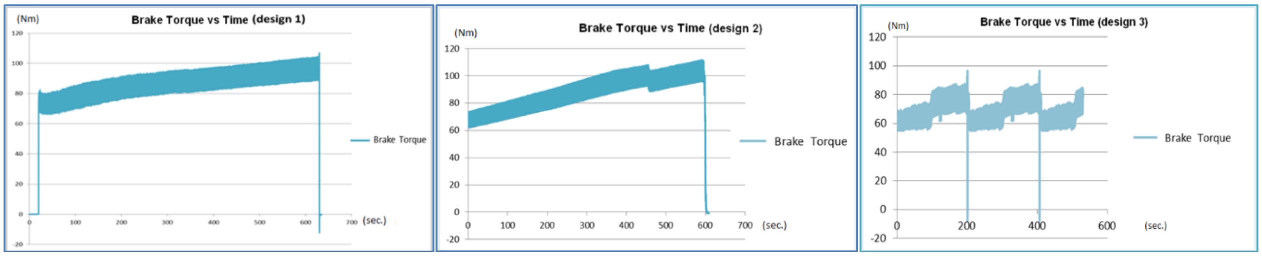
This experiment used standard grey cast iron disc that was attached to arotating shaft. Each brake pad design undergoesthe experiment with constant sliding speed of 40 rpm at three different brake pressures of 0.5, 1.0 and 1.5 MPa. Each test was run on a brake dynamometer as shown in Figure 2 for the duration of 10 minutes. The brake torque and friction coefficient results were recorded on a data acquisition system. The surface roughness and surface topography analysis and the wear of brake pad materials was measured by weighing the pad before and after each experiment using electronic balance.

■3.0 RESULTS AND DISCUSSION

3.1 Brake Torque and Friction Coefficient Analysis

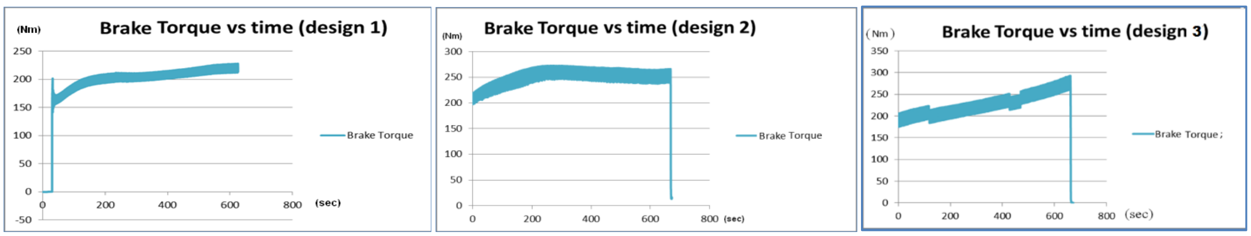
The graph in Figure 3 shows the braking torque curvesof Designs 1,2 and 3 against time for brake pressure of 0.5 MPa. The graph behaviour shows that brake torque is time dependent and increases with time. From the three graphs it is shown that Design 2 has the highest maximum torque of 109.05Nm. The second highest is Design 1 and the lowest is Design 3. The braking torque increases with time for all the designs. However, brake torque for Design 1 increases consistently compared to Designs 2 and 3. Design 3 shows some irregularity during the test as small fluctuation of brake torque could be observed during the braking process. The fluctuation may be due to the hard particles that was present in the interface and modified the mating surfaces.

Table 1 shows the friction coefficients ontained from the experiments. Each design has different friction coefficient values due to braking pressure if 0.5 MPa. The maximum brake torque also determines the friction coefficient values. Design 2 with the highest brakingtorque has the highest friction coefficient of 0.343.Design 1 has the second highest braking torque that is 102.69Nm,giving the friction coefficient of 0.322. The lowest torque from the three designs is Design 3 with the value of friction coefficient of 0.312.



(a) (b) (c)

Figure 3 Brake torque for (a) Design 1, (b)Design 2 and (c) Design 3, at braking pressure of 0.5 MPa



(a) (b) (c)

Figure 4 Brake torque for (a) Design 1, (b) Deisgn 2 and (c) Design 3, at braking pressure of 1.0 MPa

At 1Mpa braking pressure (Figure 4) the braking torque showsa similar pattern of due to the hard particle and the pad design effects. The graph shows that Design 3 generated the highest braking torque with 289.05Nm. This is followed by Design 2 with a maximum braking torque of 270.22Nm. The smallest brake torque was by Design 1 with braking torque of 214.33Nm. Similar to the 5 bar test, Design 3 shows some fluctuationsin brake torque during the braking process. The fluctuations may be caused by the external particle that changed mating surfaces, butsome got trapped in the channel of the pad. This is good evidence that pad design with channel or groove can generate high torque but with some fluctuation.

Table 2shows the friction coefficientsfor the experiment using 1.0 MPa braking pressure. The results show that Design 3 has the highest value of friction coefficient with 0.454 followed by Design 2 with 0.424 and the smallest is Design 1 with 0.337.

Table 1 Maximum brake torque and friction coefficient at 0.5 MPa

Design	1	2	3
Maximum braking torque (Nm)	102.69	109.05	99.35
Friction coefficient, (μ)	0.322	0.343	0.312

Table 2 Maximum brake torque and friction coefficient at 1 MPa

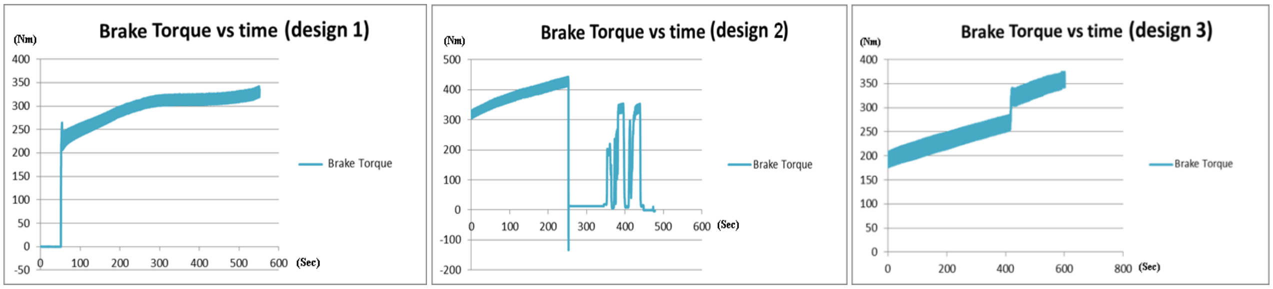
Design	1	2	3
Maximum braking torque (Nm)	214.33	270.22	289.05
Friction coefficient, (μ)	0.337	0.424	0.454

Figure 5 shows the results of the tests at braking pressure of 1.5 MPa.The results show that the highest maximum braking torque among the designsoccurred withDesign 2 with the value of 415.03Nm. The second highest is with Design 3 with 369.13Nm. The smallest value is with Design 1 with 340.14Nm. However, Design 2 shows irregularity in the result because of the seizure of dynamometer where the disc stops during the experiment after 250 seconds. Interestingly, Design 3 does not fluctuate much as what happened in 0.5 and 1.0 MPa test. The result of brake torque and friction coefficient is recorded in Table 3.

Result from the experiment for braking pressure of 1.5 MPa (Table 3) shows that the value of friction coefficient for Design 1 is 0.340, for Design 2 is 0.415 and for Design 3 is 0.386. From Figures 3 to 5, the brake torque results show that the brake torque increase with braking pressure for all the designs tested. Design 2 with a straight channel gives the highest increase in brake torque with small fluctuations. Design 3 gives second highest brake torque, but also produce some fluctuations. Design 1 gives a smooth increase of brake torque, but the value is the lowest among the three designs. Table 1 to 3 indicate that friction coefficient values change with the amount of brake torques, but do not necessarily increase with the pressure applied because it depends on the effective contact surface of the brake pad during the experiments. The effective contact depends on the pad design as the channel will modify the distribution of contact properties, especially when there are foreign particles and wear debris present on the interface.

3.2 Wear Analysis

From table 4 it is shown that Design 2 has the smallest value of wear compared to the other two designs in all three different pressures. Design 2 only lost 0.00001g/min for all the tests. This shows that even with the influence of the hard particles,Design 2 still can withstand the braking force from the piston and put it on the brake disc with minimum wear. Design 3 also shows remarkable results with an increase in wear rate only when 1.5 MPa of braking pressure was applied,at 0.00002 g/min. Design 1 started to wear at 0.00002 g/min even when only 1.0 MPa braking pressure was applied. These results indicate that the pad with channels can assist in reducing the wear of the pad as they modified the wear particles and friction film present on the brake interface. The channels helps to trap the wear particles and wipe away the friction film.



(a) (b) (c)

Figure 5 Brake torque for Design 1, 2 and 3 at braking pressure of 1.5 MPa

■4.0 CONCLUSION

In this experiment, brake pad of design 2 with straight channel in the middle show better result compared with the other two designs. Design 2 has the highest brake torque generated with the most stable and consistent increase in friction coefficient. Also design 2 resulted in smallest wear rates at 0.00001 g/min at all the tested pressures. This test shows that design 2 is better compared to the other two designs in providing better friction and wear characteristics.

Table 3 Maximum brake torque and friction coefficient at 1.5 MPa

Design	1	2	3
Maximum braking torque (Nm)	340.14	415.03	369.13
Friction coefficient, (μ)	0.340	0.415	0.386

Table 4 Pad weight loss for all three design at 0.5, 1.0 and 1.5 MPa

Design / Wear rate, g/min	1	2	3
Test 1 : 5 bar	0.00001	0.00001	0.00001
Test 2 : 10 bar	0.00002	0.00001	0.00001
Test 3 : 15 bar	0.00002	0.00001	0.00002

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